THE HORIZON OF DRUMLIN, OSAR AND KAME FORMATION.

In an article in the first number of this journal on the nature of the englacial drift of the Mississippi basin, I endeavored to show by evidence drawn from a wide area of the interior that erratics dislodged from the summits of the hills of crystalline rock in the northern region by the Pleistocene ice-sheet were borne south within the ice in such a way as to be kept separate from the basal material throughout the whole course of their transportation, and that they were at length let down upon the surface of the basal drift at the margin of the ice as a separate deposit. The evidence seemed to force the view that the basal material was not carried upward by transverse ice currents even into the heart of the glacier much less to its surface. The facts there cited seemed to make it clear that there is not only a theoretical but a practical horizon of demarcation between the englacial drift and the basal drift, and that under circumstances of this kind—and they seem to have wide prevalence—there is little or no confusion of the two. Very possibly this conclusion does not hold equally good in very hilly or mountainous regions.

In carrying out into further application this distinction, it seems well to specify the precise sense in which the term englacial is used. It may be applied to any erratic material that, at any time during its transportation, may be enclosed within the ice even though it be essentially at the bottom of the glacier and may have been actually at the bottom a little before and may again be at the base a little later on; or it may be applied, less technically but more significantly, to that only which is embedded in the heart of the ice and borne passively along with it free from basal influences until it is at length brought out to the surface of the terminal slope by the agency of ablation.

It is clear that all erratic material as it was brought to the front edge of the ice appeared either on the surface or at the base. There is here a sharp physical horizon of demarcation. If the material that had been basal some distance back from the edge was carried up to the surface, or carried up so far into the body of the ice that the surface was brought down to it by ablation near the border, it is evident that it must have become commingled with that which had been englacial or superglacial from the moment it was dislodged from its parent hills, and hence this horizon of demarcation would not distinguish between the two classes of material as such. The distinction would rest upon mode of transportation and deposition. But if the interpretation of the article referred to is correct and holds good generally in similar regions, the horizon becomes a plane of separation between the classes of material as well, and assumes much importance in practical glaciology. It was, however, obviously not an absolute plane of demarcation, even at the border of the ice, and when we attempt to apply it to sections lying farther back, it needs some qualification.

Without doubt material which was picked up by the ice along its base was thrust up into it to greater or less heights. As a particular instance, beds of rock which were inclined upward toward the oncoming ice were obviously disposed to thrust themselves into it as they were being tilted out of their positions. They appear to have rotated upon their lower edges, as upon a hinge, and were probably only removed from their places after they had been turned into a vertical position or perhaps somewhat beyond it. They were then almost wholly embedded in the ice, and so, in a limited sense, they were englacial. So also it is extremely probable that, in the case of undercut ledges, sharp ravines, narrow gorges, and similar very abrupt inequalities in which the surface was suddenly depressed, there was more or less overriding of the basal currents of the ice and consequent incorporation or overplacement of the material held in the bottom of the overrunning portion. But notwithstanding the fact that this material became englacial in a limited sense, because

it was not absolutely at the bottom of the ice, I think, in a genetic view, it is to be regarded as basal unless it was lifted so high into the body of the glacier as to be borne onward thenceforth entirely within the body of the ice and free from basal influences so that it was at length carried out to the surface as it approached the terminal edge, and was deposited as superglacial material. If the material remained approximately at the bottom of the glacier and again descended to the absolute base of the ice, it seems to me best to regard it as basal, even though it may be, for a time, completely enveloped within the ice. This seems best, because it represents the significant factor in the operation. In origin, it was basal, and, in the end, it became basal. It was only englacial by accident, temporarily.

Opposed to the agencies that tended to carry material from the absolute bottom of the ice into its basal portion to limited heights, there were several agencies that tended to bring it back to the absolute bottom. (1) The conduction of internal heat contributed slightly to this by melting away the base of the ice. The annual amount was undoubtedly very small, but the cumulative effects upon the bottom of any particular column of ice during the last five hundred miles of its journey (and this much is involved in certain aspects of the problem) was probably very appreciable and was manifestly greater in proportion to the slowness of the ice movement. (2) Basal friction undoubtedly gave rise to a much larger wastage and so lowered the embedded debris. (3) The introduction of warm waters from the surface, through the agency of crevasses, also caused wastage of the bottom, but this was obviously limited to such portions as were accessible to these waters and the effects were unequally distributed, although the positions of the streams undoubtedly changed from time to time, and this tended to spread the effects more generally over the bottom. (4) It is probable that there was a certain amount of penetration of solar rays through the ice. As the surface of a glacier is usually granular, only a minor portion of the sun's rays probably succeeded in penetrating to the transparent ice below. But such portions as reached this

were competent to traverse very considerable depths of ice without being entirely absorbed, being chiefly waves of short vibration. Those who have been beneath glaciers have observed that the amount of transmitted light is not inconsiderable. The transmitted rays of short vibration, so far as they reached the bottom, were arrested and, by transformation to rays of longer vibration, brought to bear upon the base of the glacier. The basal wastage from this source may be presumed to have increased somewhat in proportion as the ice thinned towards its margin, but this would be offset to some degree by a probable increase of surface detritus that would cut off the rays. The combined effect of these agencies would appear to have been not inconsiderable.

(5) In any vertical section of a glacier the lagging of the basal portion causes the plane of the section to lean forward, which means that each part is brought nearer to the bottom, carrying with it whatever material is enclosed. This being a general phenomenon justifies the conclusion that the tendency of the ice of the interior of a glacier is to flow obliquely forward and downward. Exceptions to this may be found when the resistance of a given portion of the base is greater than that of the portion immediately in its rear, in which case the latter may tend to flow over the former, but this will be reversed when the ratio of resistance is changed and would be, at most, but a variation of action, not a general law of action.

The combined effect of all these agencies was, if I reason correctly, to bring back to the base of the ice any material that owing to the special causes named, or to others, had been forced up into the lower parts of the ice. They tended to preserve the basal character of whatever had once become basal. And this seems to be supported by observations on existing glaciers.

These considerations have a very specific bearing upon the horizon at which drumlins, osars (eskers), and kames were formed. These all contain large quantities of local material, of basal derivation. If the view here stated is correct, these must be very strictly basal deposits, in general. There are doubtless

some qualifications and exceptions. This conclusion is not at all new, for, as is well known, it has been reached by several students of these phenomena quite independently. But an approach to the question along the line of evidence presented by *bowlder belts* and *bowlder trains* has its own advantages. It bears particularly upon a new view of the origin of drumlins recently advanced by one of our most experienced glacialists in which they are held to have been chiefly formed from englacial drift which "had become superglacial by ablation and was afterwards enclosed as a stratum within the ice-sheet, being thence amassed in these hills."[1]

In the midst of the drumlin area of south-central Wisconsin, there arise from beneath the Paleozoic strata a few scattered knobs of quartzite and quartz-porphyry from which erratics have been derived and borne away to varying distances, constituting bowlder trains of the most definite type. These are radically different from the bowlder *belts* discussed in my previous paper. The quartzite outcrops near Waterloo, in Jefferson County, are the most favorably situated for the purposes of the present study, because they are right in the heart of the most pronounced drumlin area and have made large contributions to the erratic content of the drumlins themselves. My associate, Mr. I. M. Buell, has been engaged for some time in a very careful study of the abrasion which these quartzite outcrops suffered from glaciation and of the distribution and special relationships of the erratic material derived from them. The drift movement was here to the south-southwestward and quartzite blocks derived from these outcrops enter in great abundance into the constitution of the drumlins lying in that direction. Several features of their distribution and nature are worthy of special note.

1. The quartzite bowlders are not simply scattered over the surface of the drumlins, but are distributed throughout their entire mass so far as accessible to observation. As the drumlins bear evidence of gradual accretion, it seems necessary to suppose that they were built up by successive additions of material

[1] "Conditions of Accumulation of Drumlins," Warren Upham, *American Geologist*, December, 1892. pp. 339–362.

derived from a stream of drift passing over the quartzite ledges and making constant additions from them.

2. The drumlins are found to be filled with quartzite erratics immediately in the lee of the ledges. There are even drumlins which lie directly upon the ledges and envelop them in large part, which are found free from local quartzite derivatives on their stoss ends, but are inset with them in their lee ends. The quartzite content of the leeward portion ranges, in observed sections, from 5 per cent. to 10 per cent. of the whole drift. In one case, Mr. Buell found an isolated drumlin to contain all of the quartzite of its particular kind observed in the vicinity. It evidently completely envelops the parent ledge and retains the most of its derivatives. Several bowldery mounds, that may be regarded as drumlins in miniature, occur in the immediate lee of the ledges, in which the quartzite drift was estimated to comprise from 20 per cent. to 75 per cent. of the whole. The material, in these instances, appeared to be chiefly former talus of the quartzite outcrops. Setting in thus promptly immediately at the quartzite outcrops, the erratics are found to diminish very markedly in proportion as the distance increases. A mile and a half away from the outcrops, a careful estimate of the quartzite content gave 3 per cent. of the whole mass of the drift. The average for the area between 1 and 6 miles is 1-1½ per cent.; between that and 20 miles 1 per cent.; between that and 45 miles .364 per cent., and in the terminal moraine .0477 per cent. The surface distribution shows a similar diminution. The estimated amount of quartzite on the very bowldery mounds near the ledges was 17,700 cords; at other points within six miles of the outcrops 12,650 cords; at medial points 1,409 cords; on the terminal moraine, about 45 miles distant, 747 cords. This very rapid diminution in the quantity of quartzite erratics is significant in showing that the element of resistance to transportation was an influential factor. This is precisely what is to be anticipated on the hypothesis that these bowlders were pushed or dragged along the base of the ice. It seems very far from what is to be expected, however, on the

hypothesis that the erratics rose in the ice and were transported englacially in any considerable degree. In this case, the greatest accumulation should have been at the terminal moraine where the ice halted longest. It seems to be also difficult to understand, on the hypothesis offered by Mr. Upham, how the drumlins lying immediately on the ledges and immediately in their lee could have been filled so largely with quartzite bowlders. Certainly the bowlders could not have risen in the ice so high as to have become exposed at its surface by ablation and then have been overflowed by a new accession of ice and moulded into the drumlin form, and at length have been let down by the melting of the ice beneath without more forward movement than observation shows. The simplicity of the facts do not seem to tally with the complexity of this theory.

3. The amount of abrasion which the bowlders suffered bears specifically upon the question of the mode of their transportation. The parent outcrops gave rise to erratics of three kinds. (1) In Paleozoic times the ledges stood as islands in the seas, and there accumulated about them very coarse conglomerates of quartzite. From these, a portion of the erratics were derived in an already rounded condition. The character of this rounding and the superficial changes the pebbles underwent before the glacial period made it possible for Mr. Buell to distinguish these with measureable certainty in following the train until abrasion had destroyed their surface characters. (2) Talus blocks accumulated about the bases of outcrops before the ice invasion that formed the drumlins. There was an earlier invasion which bore quartzite erratics westward. The later invasion bore them southwestward. The talus blocks under consideration are, perhaps, in the main, those that were derived from the quartzite knobs in the interval between the two. They are distinguishable from blocks disrupted by the ice by means of the weathered character of their several surfaces, so long as these remain unabraded. (3) The third class of erratics are those that were derived by direct action of the ice upon the parent knobs. These are distinguished by their unweathered fracture surfaces.

Among five hundred bowlders examined by Mr. Buell at two railroad sections, distant less than three miles from the most remote of the parent ledges, only ten were noted that did not plainly show by rounded edges and blunted angles the effects of glacial attrition. At a point less than twelve miles distant, the abrasion had so far obliterated the surface characters that it was hardly possible to determine to which of the three classes above indicated the erratics had originally belonged. Farther on, the evidences of abrasion are still more marked. The degree of abrasion did not appear to be equally great in the case of some of the bowlders found on the crest of some of the high ridges and on the surface of the terminal moraine. Mr. Buell's observations were made with the hypothesis of englacial transportation in mind as an accepted working hypothesis, but with only meagre results in the drumlin area. Studies at two points on the slope of the outer ridge of the terminal moraine and on the edge of the overwash plain gave fifty-six bowlders that were only slightly affected by glacial abrasion and eighty-eight which showed by their rounded forms and scratched surfaces the effects of severe glacial reduction. While therefore the observations do not exclude the hypothesis of a small amount of englacial transportation, if slight abrasion be taken as sufficient evidence of this, they limit it to a quite trivial factor of the whole mass.

The combined testimony of the foregoing facts seems to me quite decisive in its bearing on the proposition that the derivation, transportation and deposit of the quartzite bowlders was almost exclusively subglacial or at least closely basal. As these bowlders enter into the structure of the drumlins from base to summit, and are mingled with much other local material, the foreign element being relatively small, they seem to compel the same conclusion respecting the whole of the material which was built into the drumlin forms.

Mr. Buell has found what he regards as satisfactory evidence that an older train of bowlders was carried directly westward at the time of the earlier drift and that the later ice movement toward the southwest crossed this train obliquely and distributed

it over a much greater area than it originally occupied, forming a secondary train. The erratics of this secondary train, he finds much smaller in general and marked by greater evidence of glacial reduction than those of the unmodified later train. This has a double bearing upon the question of the origin of the drumlins in that it indicates basal transportation in both epochs and in that it indicates a direct accumulation of the drumlins *de novo* during the later incursion. It seems to exclude the view that the drumlins are remnants of the older drift; for, since the older train was westerly, there would be no quartzite material in the old drift lying southwesterly from the outcrops, and hence none would appear within the body of the drift in that region when worn into drumlin forms. But it is just here that quartzite erratics appear in their greatest abundance and permeate the body of the drumlins most impartially. The direct south-southwesterly bowlder train is so predominant that the older, and now more scattered, westerly one was not recognized by the earlier observers.

The testimony of these *bowlder trains* (basal phenomena distributed along the line of drift movement) combined with that of the *border belts* (superficial phenomena distributed transversely to the drift movement and parallel to the edge of the ice) seems therefore to add some special weight to the already familiar evidence supporting the view that drumlins are strictly basal aggregations.

There are no well defined osars (eskers) in this drumlin region, but there are tracts of gravelly knolls and ridges some of which seem to represent longitudinal glacial drainage lines, and so, genetically speaking, to stand for the esker phenomena. Aggregates of the kame type, or of an unclassifiable type of this general order, occur not infrequently among the drumlins. In connection with the moraines bordering the district, kames of the typical variety have an abundant development. Into all these, so far as they lie within the area of quartzite distribution, the quartzitic material enters in even greater abundance than into the average unmodified till of the drumlins themselves or

of the moraine. The mean of several observations upon kame-like accumulations of gravel lying within ten miles of the parent outcrops gave Mr. Buell 5 per cent. of quartzite, in the interior material accessible in sectional exposures. At points about midway between the parent ledges and the terminal moraine, forty-five miles distant, the average amount was found to be 1.2 per cent. Measurements made nearer the limit of the later drift showed .39 per cent., while on the margin, the quantities were usually found too small to be estimated in percentages.

It thus appears that the law of distribution found in the drumlins holds good for the kames save that the relative percentage of quartzite in the latter is greater than in the former; a fact which finds its explanation, in part certainly, in the fact that the clayey and other fine material of the drumlins enters into the estimate of percentage for them while it does not in the case of the kames, it having been chiefly washed away; and perhaps also, in part, in the fact of greater resistance to wear on the part of the quartzite.

These kame-like accumulations sometimes lie in the lee of the drumlins and form a part of the common hill or ridge, their contours blending into the common contours of the drumloid form, so that there can be no doubt that the two portions were simultaneous in formation, and that the horizon and environment of their accumulation were identical. In other instances, they are associated with cols or with valleys among the drumlins in such a way as to leave no doubt that the kames and drumlins were closely associated and essentially contemporaneous in formation. As some of these kame-like forms lie very near the parent quartzite ledges, it seems quite impossible to suppose that the quartzite erratics were borne to the surface by internal cross movement of the ice, and afterwards let down so near to the origin of the material as we find them. There seems, therefore, no escape from the conclusion that these are also very strictly basal phenomena, being but assorted and re-aggregated portions of the common drift of the drumlins and the general ground moraine.

Returning to the region of the superficial bowlder *belts* in Illinois, Indiana, and Ohio, we find hillocks of the kame type distributed throughout the same tracts as the bowlders, indeed, practically lying beneath the bowlder belts themselves. Some of these I described nine years ago in the American Journal of Science in an article entitled "Hillocks of Angular Gravel and Disturbed Stratification."[1] Additional evidence of the same import has been since gathered. Among the materials of these kame-like aggregates, it is not uncommon to find a complete series of gradational forms, ranging from incorporated masses or tongues of typical till of the ground-moraine type, through partially modified masses and layers of half-till, half-gravel, to completely assorted and stratified material, thus showing every stage of the derivation from the common underlying and surrounding till. The attrition of the material shows a like gradation. In some portions the clayey constituents of the till have been simply washed out leaving the rock fragments which show almost no perceptible wear from water. In others, the rounding has been more considerable, and in still others, there has been a reduction to the common rounded gravelly type. Even this is not usually well rounded. The less modified fragments not uncommonly show glacial striation. All these variations occur within the limits of a single hillock, and are often so intimately associated as to compel the conviction that the gravel is but a partially assorted derivative from the till of the region. In some of these hills the stratification is disturbed, not as though the beds had been let down by the removal of ice below, but as though they had been pushed horizontally by glacial pressure. The essentially local derivation of the material is demonstrated by the very notable presence of rock fragments derived from the formations of the neighborhood. More than half the material is not infrequently made up of limestone whose origin must be much nearer at hand than that of the superficial bowlder belt. An analysis representative of the gravel and sand of one of these kames gave as much as 70 per cent. magnesian limestone.

[1] Am. Jour. Sci., vol. XXVII, May 1884. Pages 378–390.

It is probably safe to say that in selected instances at least 90 per cent. of the material was derived from the Paleozoic series and more than half of this from the vicinity. This is, however, too large an estimate for the average, but the local constituents were never seen to be other than pronounced if not predominant. Material of local derivation also enters into the constitution of the sand and clay as well as the coarser material showing that the hillocks are made up not only of the glacially ground rock-fragments, but of the glacial grindings. The whole aspect of the material of these kames is so strikingly in contrast with that of the superficial bowlder belt and points so definitely to their derivation from the common sheet of subglacial till as to seem to put beyond doubt the view that they are quite strictly basal in formation.

Osars of the typical variety have comparatively few representatives in the plain tracts of the interior, but several well characterized instances occur. It is notable that, in most of these instances, as pointed out by Mr. Leverett, who has perhaps carefully studied a larger number of them than anyone else, they often lie in river-like channels cut into the till sheet of the region. There are perhaps a dozen of these that have been studied, varying in length from a few miles to about fifty miles. These channels have the characteristics of river troughs, and usually stand so related to the margin of the ice as to seem to indicate that they were lines of subglacial drainage during the same glacial stage as that in which the osars were formed. These channels are so related to the surface slopes that they could not have been formed by free open-air streams. The restraining aid of ice seems necessary. While no demonstration of the history of their formation can be claimed, the most plausible explanation appears to be that the river-like channels were cut by subglacial streams at a time when the urgency of the ice was such as to compel basal cutting, and that, subsequently, when the pressure of the ice was less insistent, and its motion feebler, the draining stream was permitted to fix its channel in a tunnel cut in the under surface of the ice, which

otherwise occupied the channel previously cut, and that the stream gradually built up its gravels within the tunnel so formed, essentially as indicated by Professor Russell in the case of tunnels under the Malaspina glacier. While the inferences drawn from this peculiar association of the osar ridges with river-like channels cannot be urged with the same force as the preceding considerations, they seem to support them in some degree. The constitution of these osar ridges is of the same local character as that of the kames above discussed except that perhaps it is less narrowly local and less intimately related to the underlying formations. The difference, however, is not marked.

From the foregoing evidences, the inference is drawn that the osars and kames of the plain region of the interior are basal phenomena in a degree almost as complete as the drumlins or the ground moraine. Inferences from such evidences as have been cited cannot, however, be applied with so much rigor in the case of osars and kames as in the case of drumlins, for the subglacial streams, that are held to have formed them, cannot be assumed to have always pursued strictly basal courses. Conditions may be supposed to have arisen which would have forced the streams into channels above the base of the ice, or even up over the ice in the thin marginal portion, so that accumulations may have taken place that were less strictly basal than those of the drumlins, and it is of course possible that kames and osars may have been formed, in particular instances, out of the englacial and superglacial material of the ice; but, following what seems to me the legitimate teachings of the foregoing lines of evidence and of observation, there seems warrant for concluding that such instances, though theoretically possible, are practically rare. I beg that it may be observed that these conclusions are drawn from the phenomena of the plain region of the interior and are applied to it, with the full recognition of the possibility that in hilly and mountainous regions modifications of the conclusions may be necessary.

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